Avionic Systems Division
Engineering Directorate
NASA–Johnson Space Center

International Space Station (ISS) External High Definition Camera Assembly (EHDCA)

In-Space Inspection Technology Workshop

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Victor Studer
Avionic Systems Division

External High Definition Camera Overview

- International Space Station (ISS) program requested Engineering to provide an external high definition (HD) video capability to view Earth and ISS.
  - Integrated as part of the ISS Communications and Tracking System
  - Directional pointing provided by the Pan and Tilt Unit (PTU) of the External Television Camera Group (ETVCG).
  - Receives commands and sends imagery, health and status through the External Wireless Communications (EWC) system.
  - Electrical power is from sharing ISS supplied power to the Video Camera Luminaire (VCL) heaters (120VDC).
  - EHDCA can be installed either IVA or during EVA.
  - Control of the EHDCA is from the Mission Control Center (MCC)
  - Commercial Off the Shelf (COTS) hardware based.

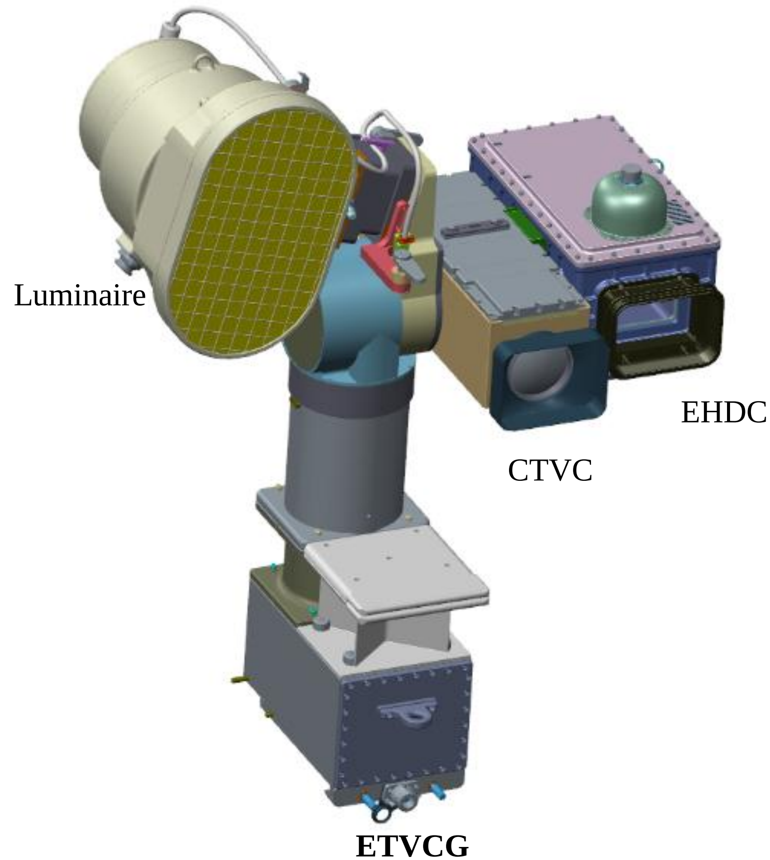

Figure 1: ETVCG Assembly w/EHDC

EHDCA Installation Locations

- Flight units to be installed at each camera port location – CP3, CP8, CP9 and CP13

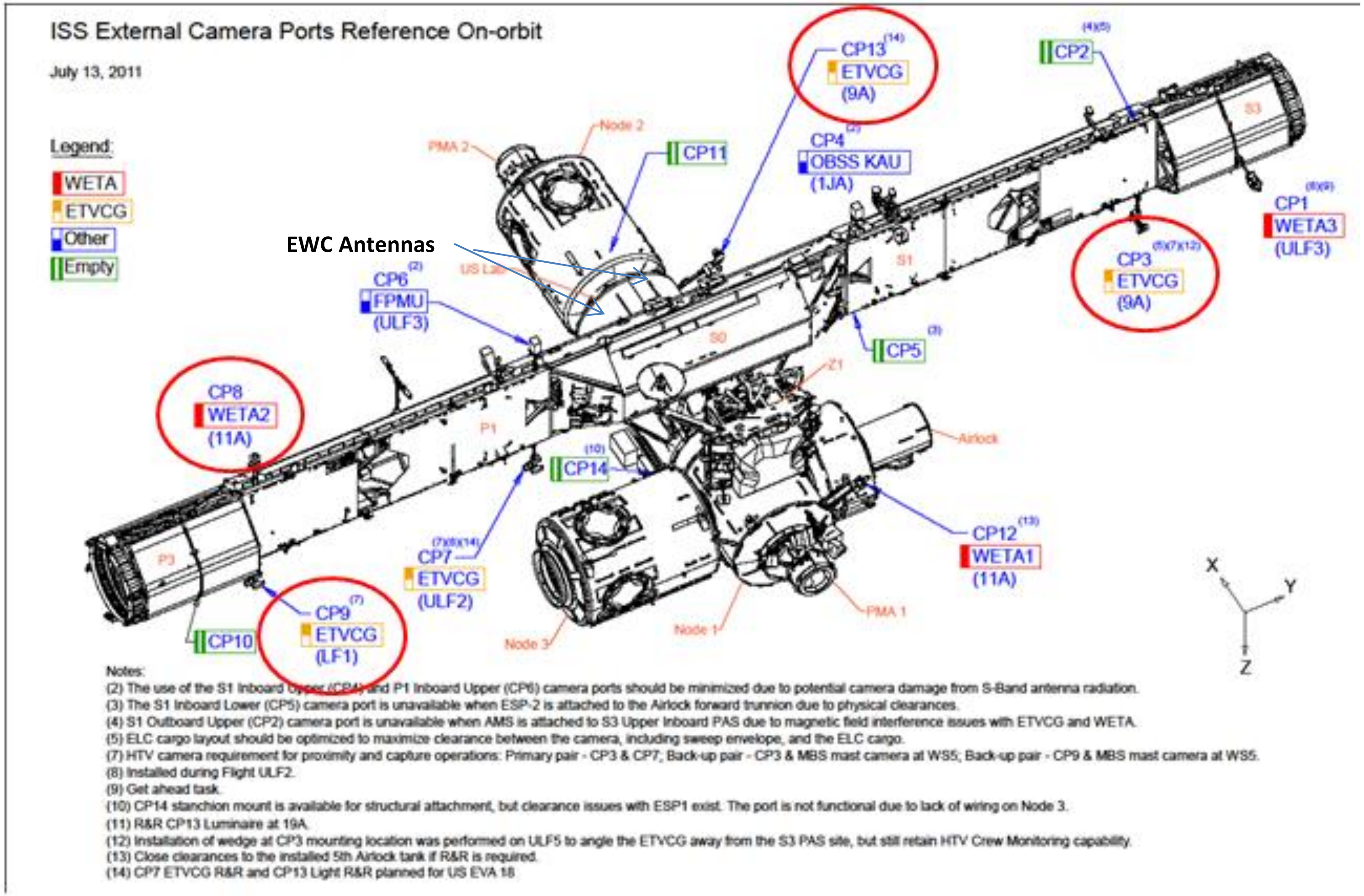

Figure 2: ISS Camera Port Locations

External High Definition Camera Overview

- EHDCA Constraints/Requirements
  - Weight and volume limits (< 30 lbs and limited envelope)
  - EVA compatible for installation and removal.
  - Power Limit <248 watts (later lowered to ~200w)
  - Provide standard (NASA-STD-2818) HD Video (720P60)
  - Controllable zoom lens
  - Provide minimum of 2 years of operational life
  - Conform to EWC wireless Ethernet based communications (802.11n, 5.2 GHz) WiFi compatible system through the ISS Joint Station LAN (JSL)
  - H.264 compression with MPEG2 transport stream HD video
  - Must provide high quality HD video views of ISS and Earth, inspection is not a requirement of this system
- EHDCA Goals
  - Provide imagery if Airlock, HTV Capture and Node 2 Nadir activities (RF coverage)
  - KX/Imagery Analysis Group provided list of Desirements
    - Provide ‘wide’ field of view zoom of 5^{o} to 75^{o}
    - Provide 2 - 4 pixels/0.1 inch resolution at 267.5 feet (Camera/Lens selection)
      - 1280 x 720 pixel HD resolution this equates to ~ 1.2 degree Horizontal Field of View (HFOV).
    - Automatic control (iris, focus, gain, white balance etc.) with manual override
    - Metadata & telemetry downlink
    - Three chip sensor system camera (no Bayer pattern)

EHDCA Architecture

EHDCA Integrated System Architecture

- EWC compatible radio and antennas operating in Client mode
  - EWC Wireless Access Point (WAP) radio couldn't be used
  - New radio had to be qualified for EHDC (Boeing provided)
    - Based on Moxa AWK-4131 radio
    - Ruggedized and updated firmware to increase power output over standard model
  - Circular polarized, wide beam, small, 5.3 GHz antenna required
- Camera & Lens selection trade study
  - Ethernet based control was significant factor in trade
  - 720P60 high definition video output required
  - Size, Weight and Power (SWAP) limitations
- Controller for system control and status.
- Video Compression Encoder – Selected H.264 encoder recently certified for ISS internal use
- Ethernet Switch – Internal Ethernet interconnections.

EHDCA Architecture

- EWC drove need for an Ethernet based integrated video and communications architecture

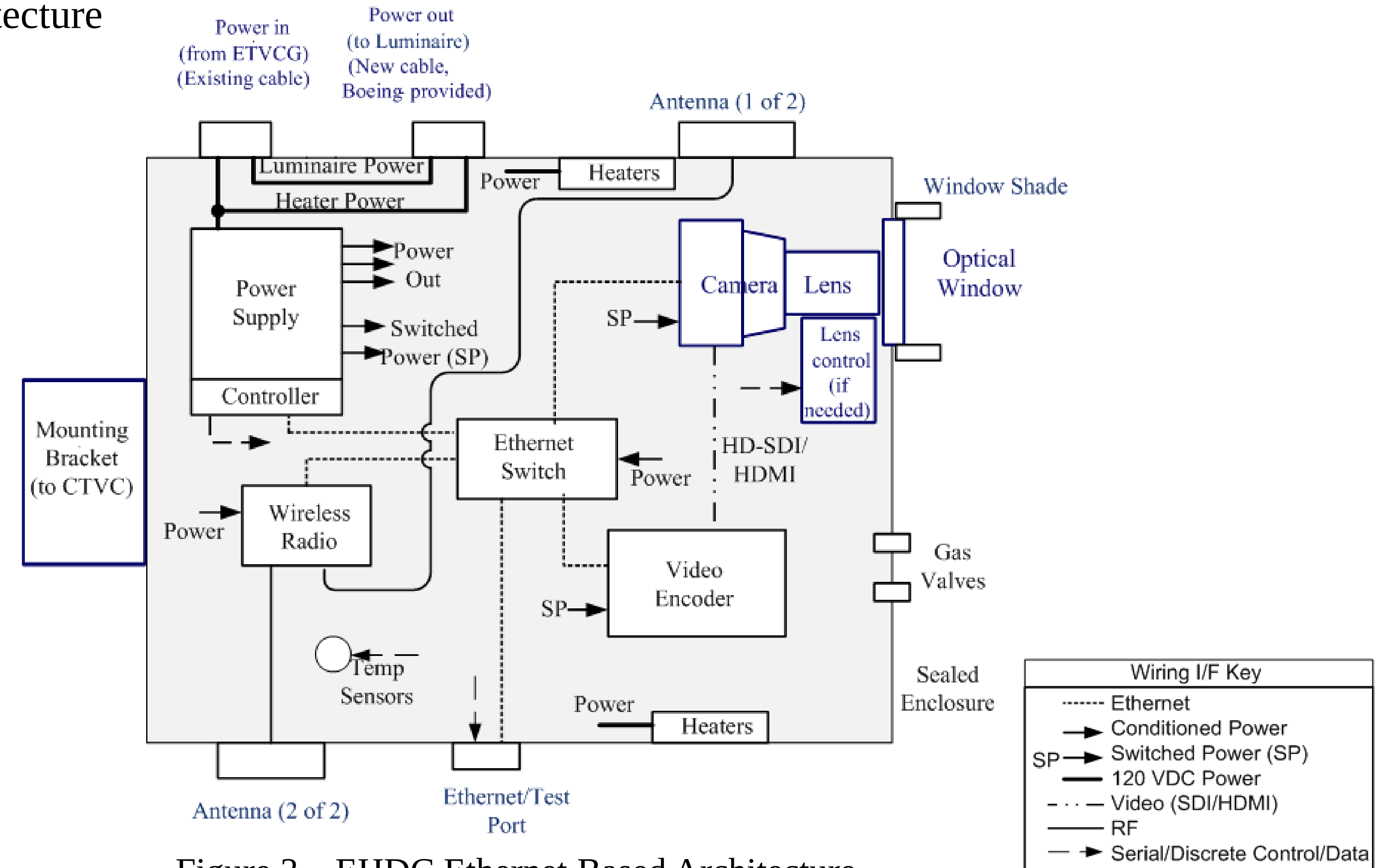

Figure 3 – EHDC Ethernet Based Architecture

EHDCA Installation Locations

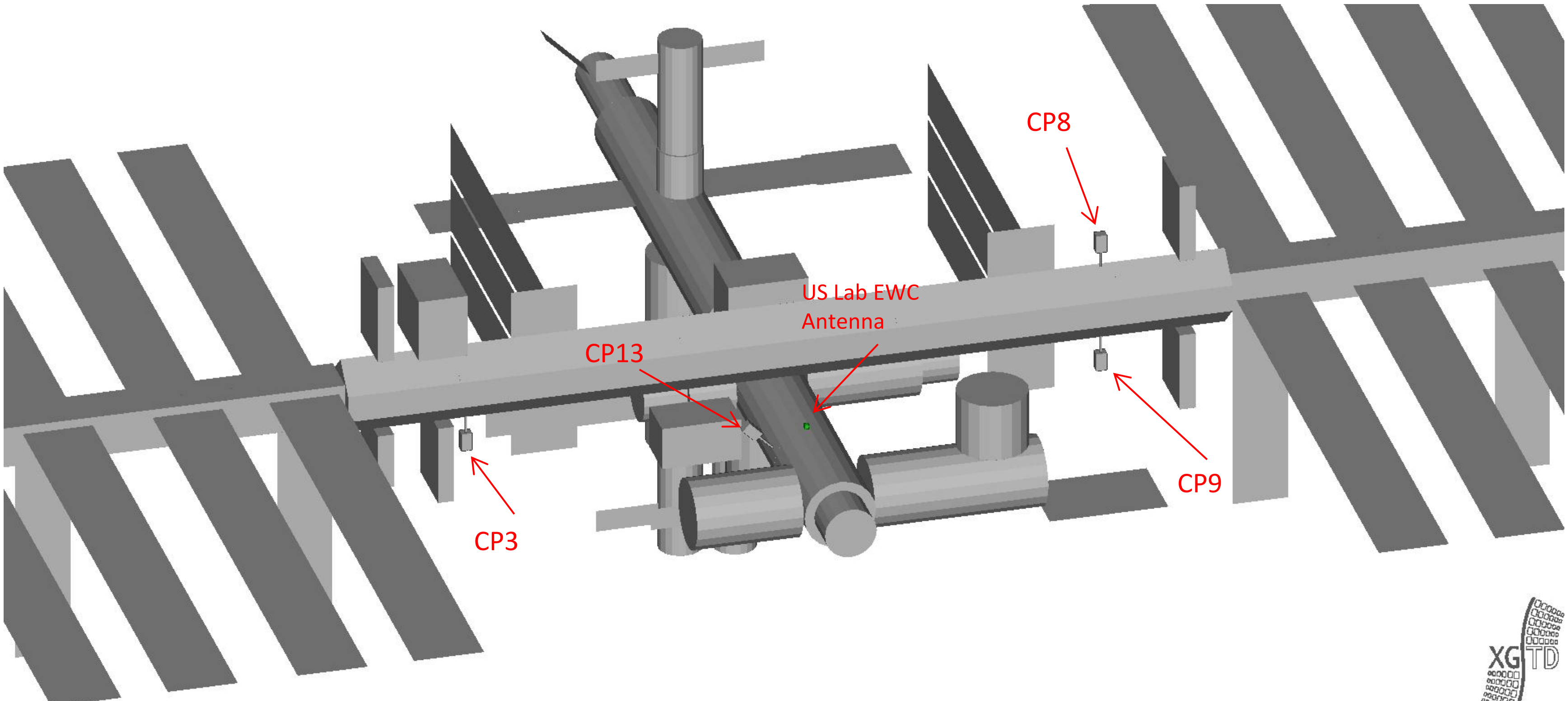

Figure 4 – Simplified CAD model of ETVCG and EHDC Locations

EHDC Architecture – Wireless Antenna Coverage

Key to success of EHDC depends entirely on our RF coverage in conjunction with EWC

- External Wireless Communications (EWC) Background
  - EWC Myers antenna test data shows irregular coverage.
  - EHDC camera locations show positive signal margins for 10 Mbps communications - just.
  - EWC antennas are linearly polarized, EHDC antennas had to be circularly polarized (-3dB loss)

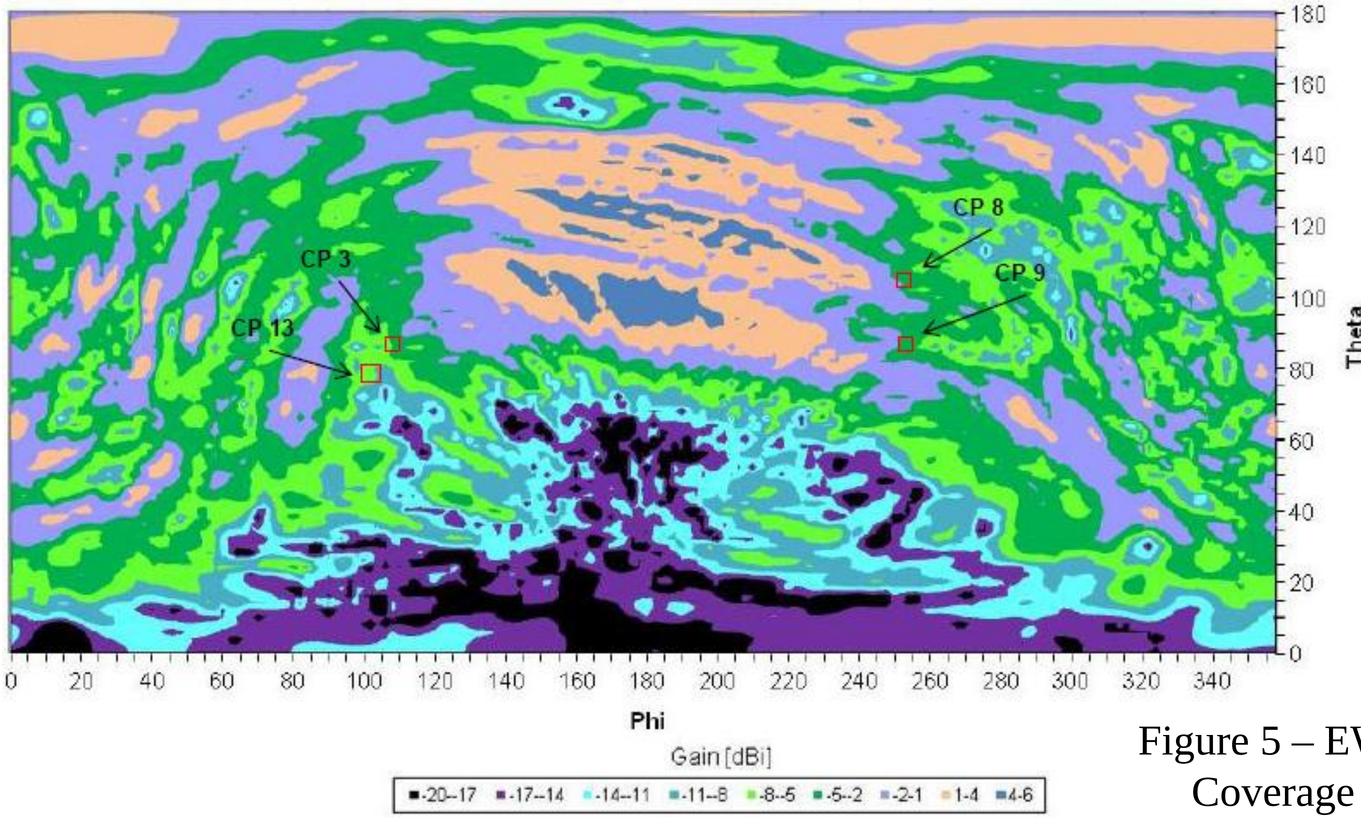

Figure 5 – EWC RF Coverage Analysis

EHDC Architecture – Wireless Antenna Coverage

- EHDC cameras will have nearly spherical imagery coverage thanks to the ETVCG's Pan and Tilt Unit.
- RF coverage is limited by mounted antennas which will move with the EHDC.
  - Antenna selection based on trade study and test of commercial antennas – best antenna gain limited to ~ +/– 30 degrees off axis, limited gain below.
  - Unique ground plane designed to improved overall coverage.
  - Antennas must be circularly polarized to work with EWC linearly polarized antennas.

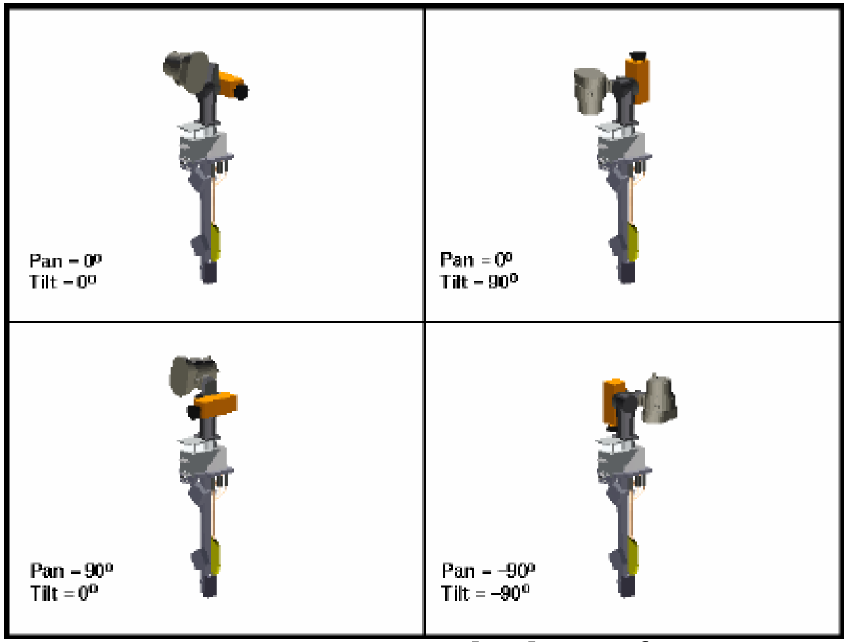

Figure 6 – Various Pan and Tilt Configurations

EHDC Architecture – Wireless Antenna Coverage

- EHDC Antenna selection/design – Antenna selection restricted to available COTS
  - Selected Tecom Cavity-Backed Spiral – Nominal 70 degree beam.
  - Beam shape depends on associated ground plane.
  - Significant study, design, analysis and testing effort went into the final ground plane geometry.
    - Optimized gain and axial ratio

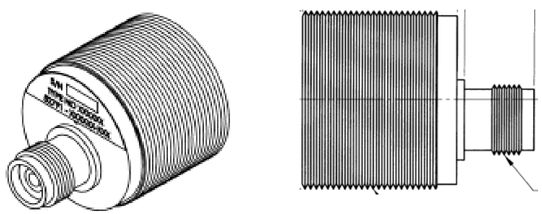

Figure 7: Tecom Antenna

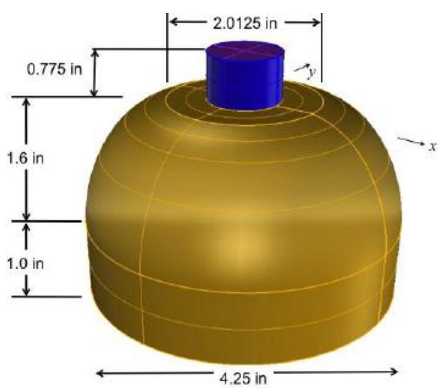

Figure 8: Final Ground Plane Geometry

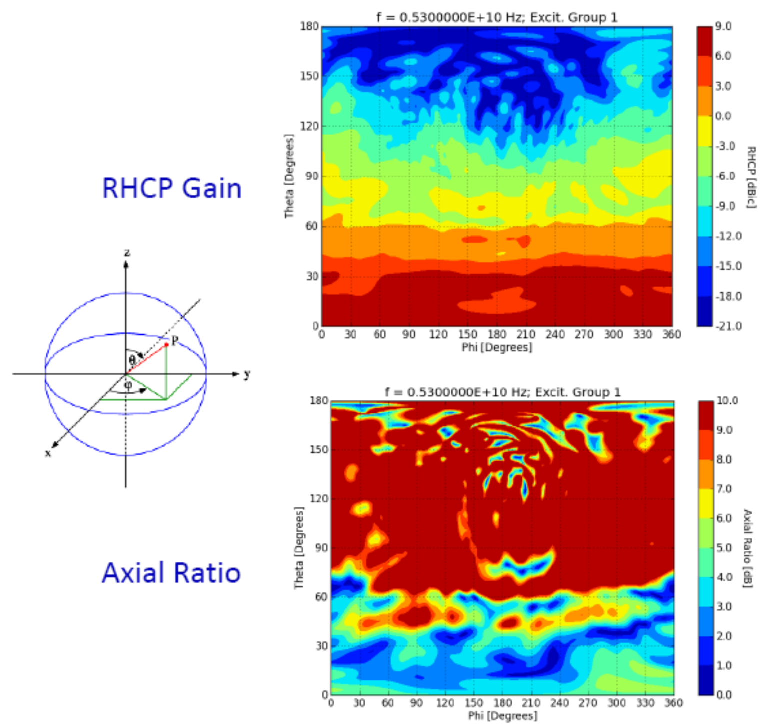

Figure 9: Ground Plane Design RF Coverage

EHDC Architecture – Wireless Antenna Coverage

- EHDC housing structure effects on antenna RF Coverage.
  - Upper Antenna mounted to flat EHDC upper lid

Figure 10 – Upper Antenna Mount

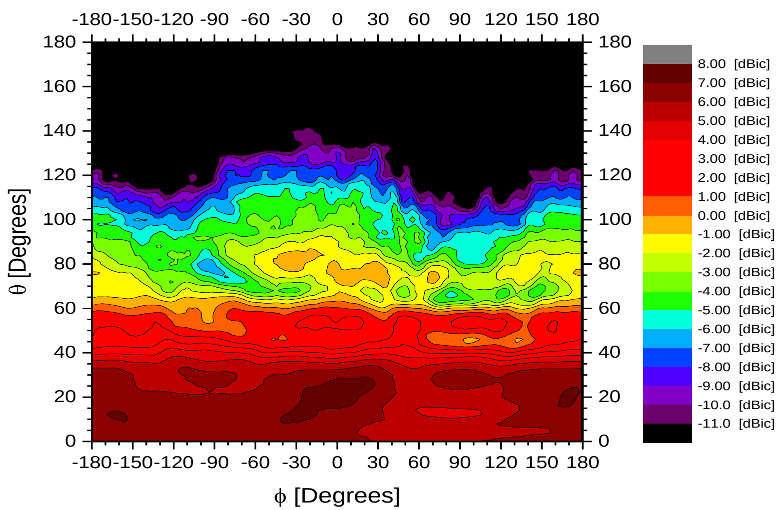

Figure 11 – Upper Antenna Measured RHCP Gain

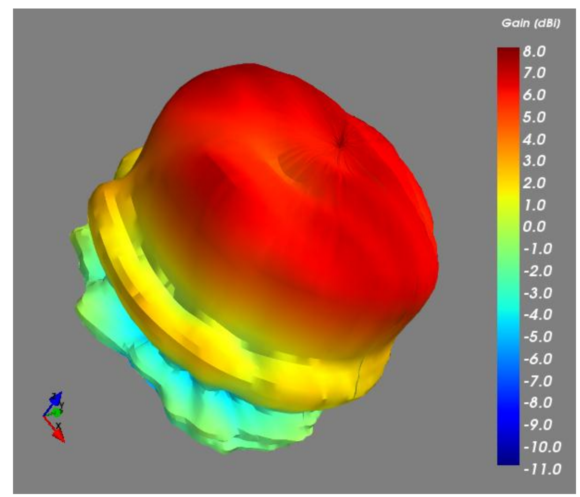

Figure 12 – Upper Antenna 3D Countour Plot

EHDC Architecture – Wireless Antenna Coverage

- EHDC housing structure effects on antenna RF Coverage
  - EHDC Lower antenna mounted to irregular lower housing structure

Figure 13 – Lower Housing Antenna Mount

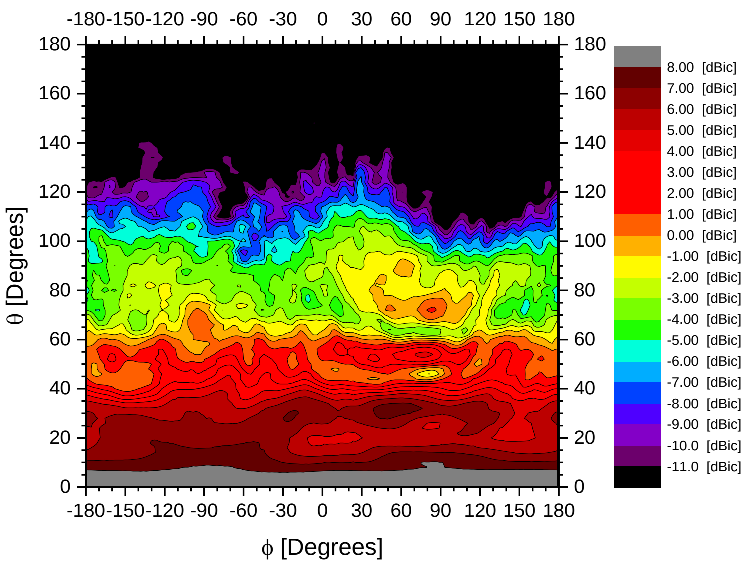

Figure 14 – Lower Housing Antenna Measured Gain

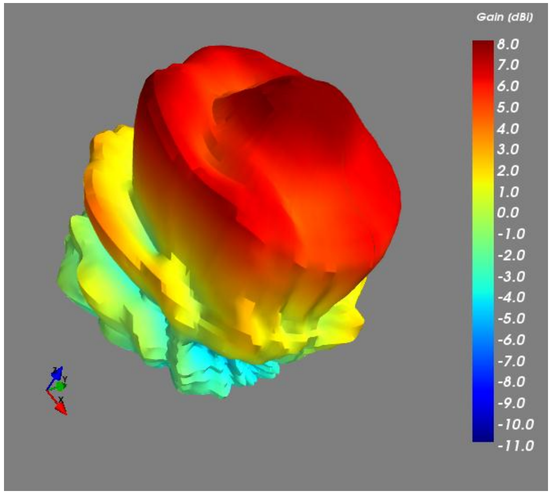

Figure 15 – Lower Antenna 3D Countour Plot

Camera/Lens Trade Study Results

- Extensive market trade study, camera evaluation and tests performed
  - Broadcast quality 3 chip box cameras and associated lenses exceed limits
  - Smaller 'Professional' 3 chip cameras underperformed and/or failed radiation testing
  - Inspection/security cameras not compatible with broadcast standards
  - DSLR camera/lenses at upper SWAP limit but none provided adequate external control capabilities
    - Nikon D4 camera undergoing testing as the next EVA camera with extensive USB control interface, Ethernet and HDMI interfaces available but with limited functionality
      - Long history of good working relationship with Nikon
      - Nikon believed camera firmware updates could be made to meet our Ethernet control and HDMI output requirements
      - All controls required for camera operation could be controlled remotely
      - Radiation performance acceptable
        - » ~95 percent of damaged pixels anneal with time
        - » Expected life due to permanent damage should exceed 2 – 4 year planned EHDC operational life
    - Other DSLR cameras required manual switch activations for basic operations
    - External zoom lens drive would have to be added for any DSLR
    - DSLR cameras have known video performance deficiencies and few fine adjustments normally found on professional video cameras
    - DSLR's are used extensively for television and cinema productions

EHDC Camera

- Nikon D4 DSLR with 28-300mm lens & 2X teleconverter selected as EHDC camera.
  - Selection based on criteria established by user community, ISS program and engineering
  - Final selection made after ‘Camera Summit’ with demonstrations of top candidate cameras
  - Nikon provided firmware updates solved original limitations.
  - 1280 x 720 progressive video mode uses slightly less than full image sensor
    - Video pixels integrated across 9 Bayer pattern sensor pixels
  - 16.2MP sensor, still camera limited to 13.6 MP (4928 x 2768 pixel) in 16:9 movie mode
  - Auto and manual focus provided through EHDC control system
  - Sensitivity ISO 100-12800 range plus extended EV settings (-.3 & +4 EV) giving ISO 50 – 204800
  - Control of all camera functions is through Ethernet port allowing full remote control
  - Camera provides LiveView mode with low data rate imagery provided through Ethernet port
    - Allows operators to view still or video imagery prior to downlink
    - Expanded view up to full resolution of sensor
    - Downlink video imagery is same as low data rate LiveView
  - External stepper motor zoom lens drive controlled through EHDC controller
    - 56 – 600 mm zoom lens gives ~ 3.4 – 36 degree horizontal field of view
    - Focus drive controlled through camera
- EHDC Control software developed for MCC operators
  - Allows full camera control, video and still picture downlinks.
  - Provides EHDC system telemetry including EWC received signal strength

Figure 16: D4 Camera w/Lens

EHDC Architecture

- Remaining EHDC Components
  - Controller – Off the shelf ASD Modular Instrumentation design
    - Power control –
      - Allows operator control to reset power to components in event of detected SEU
      - Controls standby mode (camera & encoder turned off)
    - Status telemetry (temperature, pressure, currents)
    - Watchdog timer
    - Control camera zoom lens function
  - Video Encoder
    - Visionary Solutions Incorporated (VSI) AVN443HD Encoder
    - HD H.264 encoding bit rate range 5 – 20 Mbps
    - Nominally set to 8 Mbps encoding
    - Provides standard MPEG 2 Transport Stream
  - Power Supply – 120 V power is always on
    - Power shared with Luminaire heater power
    - Primary power supply 120 VDC to 24 VDC
    - Secondary board provides separate power supplies for each component
  - Heaters
    - Thermostat controlled
    - 120 VDC direct from input power

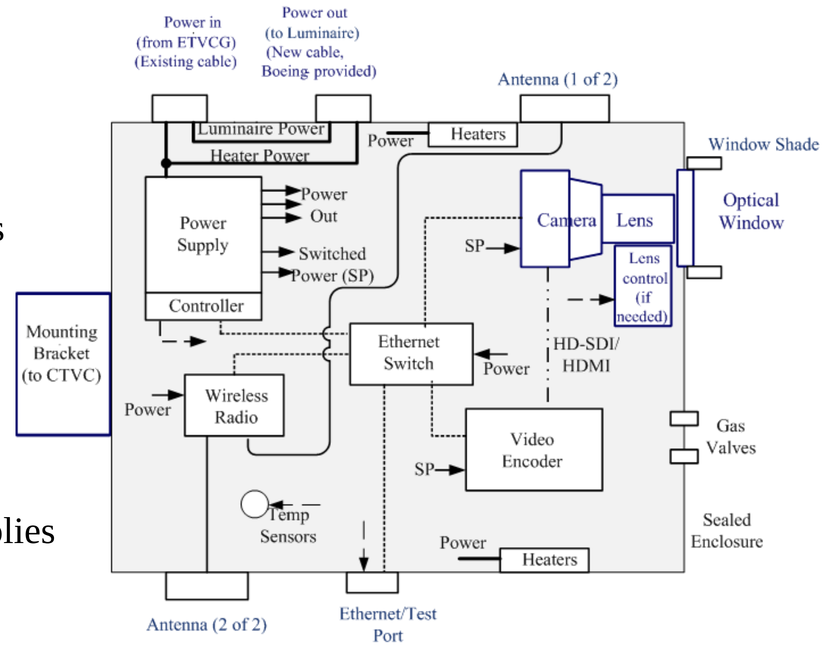

Figure 17: EHDC Block Diagram

EHDC Architecture - Enclosure

- EHDC incorporated a sealed enclosure to better protect the components
  - Dry nitrogen filled to 1 atmosphere
  - Minimize COTS component off-gassing
  - Provides better thermal control over vacuum
  - Required use of an optical window
    - Optical quality ¼” Fused Quartz
    - Anti-reflective coating on each surface
- Enclosure designed around internal components, external clearance zones, EVA installation requirements and weight limitations.
  - EVA installation/removal
    - Blind mate to current camera’s side slide rail
    - EVA compatible power connectors
    - EVA compatible interfaces (Microconical & tether loop)
  - 3D printed window and internal lens shrouds
  - Machined aluminum housing
  - Thermal reflective tape on all surfaces
  - Final weight 28.25 lbs.

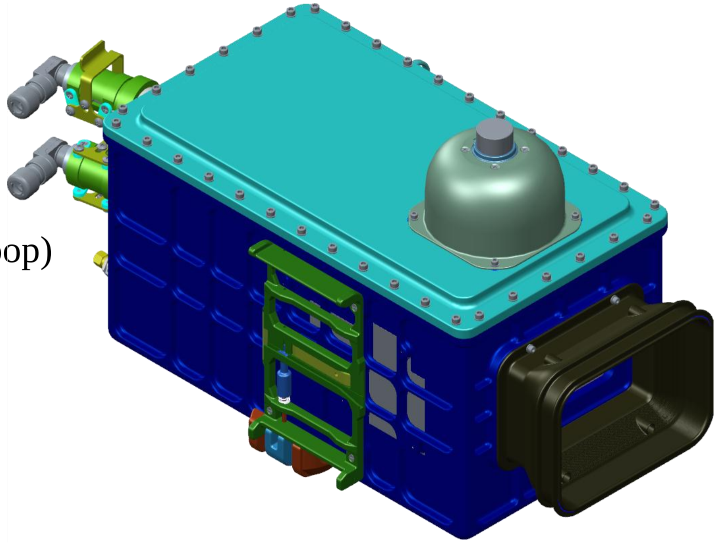

Figure 18: EHDC Assembly

EHDC Internal Design

- Internal Packaging
  - Camera, lens, zoom lens motor drive, power supply, controller mounted on ‘doghouse’

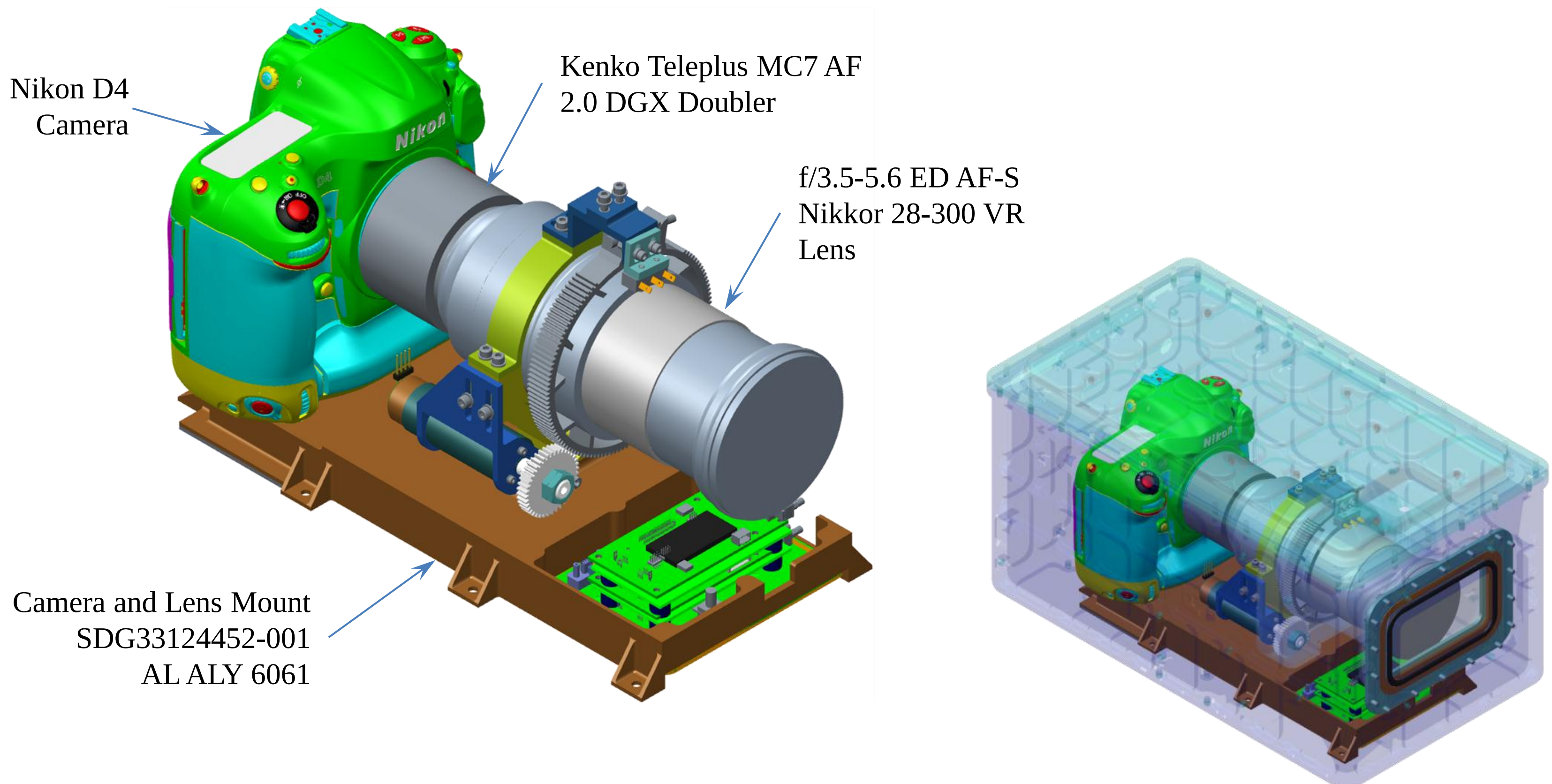

Figure 19: EHDC Camera Mount

EHDC Internal Design

- Internal Packaging
  - Doghouse assembly, encoder, switch, radio, antennas, cabling incorporated in overall EHDC assembly

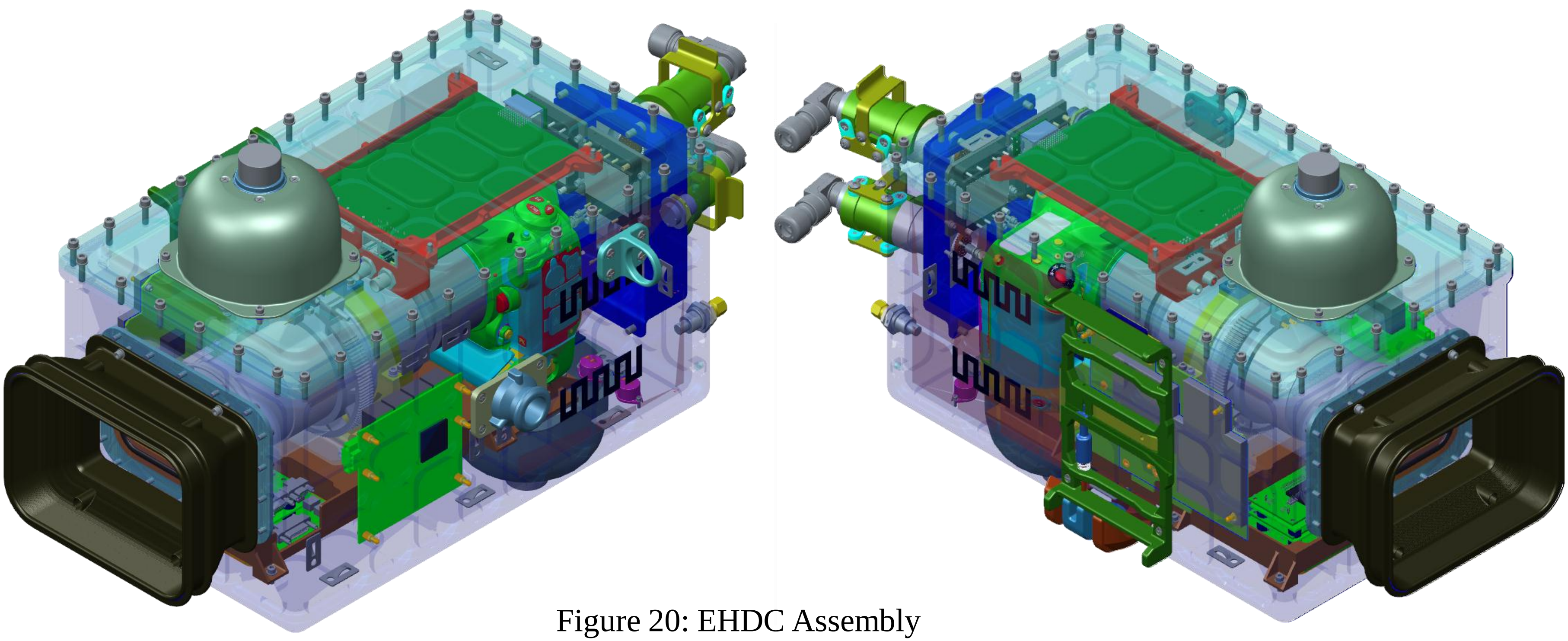

Figure 20: EHDC Assembly

EHDC Performance

- End to end camera video/encoder performance
  - Video resolution measured at Usable and Limiting values
    - Worse case (600 mm telephoto) usable resolution ~ 600 TV Lines/picture height
    - Limiting resolution ~ 690 TV Lines/picture height
  - Still imagery resolution > 2000 lines
  - Optical window has very little effect on image resolution
    - Small degradation at 600 mm, effect is greater in still imagery mode
    - Not noticeable in video mode
- Low light level operation
  - Required to work with ISS ETVCG mounted Luminaire – Specified to provide 3 foot-candle at 60 feet
  - Video low light performance limited by 1/60 sec frame rate – ISO 12800 +4EV creates grainy, noisy video image at 3fc and lower
  - Still image capture at longer integration time and optimal settings operates well below 3 fc

EHDC Performance

- Low light level still imagery

Figure 21 - 32 Lux (~3fc) Lab Image

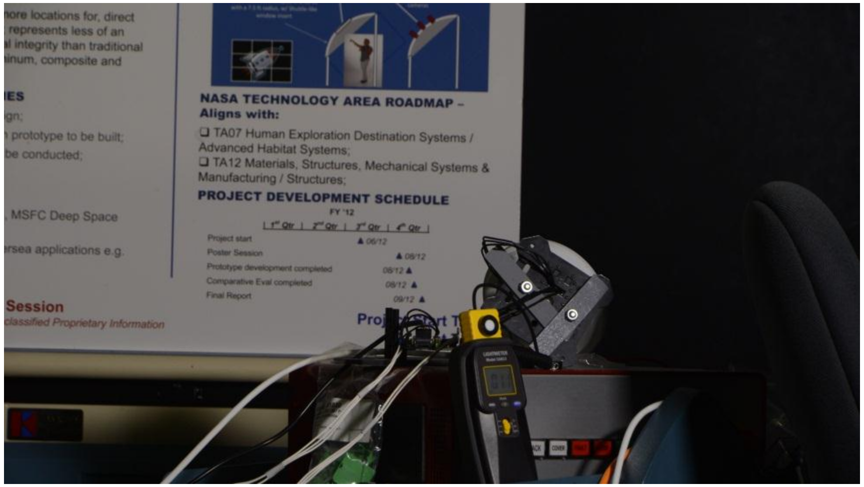

Figure 22 - 11 Lux (~1fc) Lab Image

Flight and Installation Schedule

- 2 ORUs and Cables on Orb-4
  - SpX7 BU flight
  - Support EVA D, Install CP8 & CP13 (April, 2015)
- One unit on SpX7
  - No BU Flight
  - Support EVA E-1 (June, 2015)
- One unit on SpX8
  - Orb-5 BU flight
  - Support EVA E-2 (July, 2015)